Fuel Cells: Electrochemical Devices to Generate Electricity

We are developing several approaches to fuel cells, which convert the chemical energy of a fuel directly to usable energy without combustion.

Fuel cells are widely viewed as the technology of the future to replace internal combustion engines in vehicles and to generate stationary power. The advantages are great: higher efficiencies than internal combustion engines, significantly lower emission of pollutants, potential flexibility in fuel, and no noise.

At LLNL, we are working on three different fuel-cell approaches:

- A zinc-air fuel cell that uses zinc pellets as the fuel.
- A unitized regenerative fuel cell that operates as an electrolyzer to produce hydrogen from water and as a fuel cell that uses hydrogen to generate electricity.
- A solid oxide fuel cell, fabricated from ceramic ion-conducting materials, that uses hydrogen or other combustible gas as fuel.

Although fuel cells have been used since the 1960s in space applications, the challenge today is to develop cost-effective systems that are practical for vehicles and stationary applications, such as buildings.

The Zinc-Air Fuel Cell

Our zinc-air fuel-cell technology has many advantages: high energy efficiency in relation to weight (150 Wh / kg), rapid refueling, low cost of hardware and energy, and zero tailpipe emissions.

This device combines atmospheric oxygen and pellets of zinc metal in a liquid alkaline electrolyte to generate electricity, with byproducts of zinc oxide and potassium zincate. Our novel self-feeding design, with the 1-mm zinc pellets gravity-fed from hoppers to the fuel cells, avoids the clogging problems associated with some zinc-air fuel cells. Modular design will allow scale-up for a variety of applications.

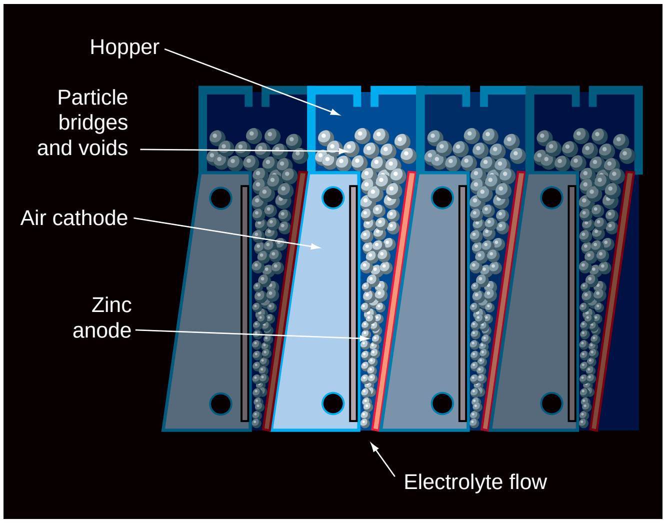
Refueling is easily accomplished—without the need for complicated, expensive infrastructure—by replacing the spent electrolyte with fresh electrolyte containing recycled zinc pellets. This makes the zinc-air fuel cell especially appropriate for fleets of buses or vans, which could operate 24 hours a day with only brief refueling stops every 250 miles or so. There are numerous potential routes to the recovery of zins pellets from spent electrolyte.

We have tested a prototype of this fuel cell under laboratory conditions and on the road and are ready to perform the R&D required for scaling up to commercial size. Mobile applications include buses, vans, off-road vehicles, and electric scooters. Stationary applications include small units for emergency power generation and uninterruptible power supply, as an alternative to gasoline or diesel generators. Larger units could be used by utilities to meet peak power demand.

We will be collaborating with an industrial partner to further develop the fuel cell and zinc recovery unit.

The Unitized Regenerative Fuel Cell

The unitized regenerative fuel cell uses bifunctional electrodes that reverse roles when switching from charge to discharge, as with a rechargeable battery. In the fuel cell mode, oxygen and hydrogen create



In the zinc-air fuel cell, the zinc pellets are gravity-fed from hoppers to cells.

electricity and water using a solid polymer electrolyte or proton exchange membrane (PEM) that is capable of transporting hydrogen ions (protons) without concentrated acids or bases. When the cell acts as an electrolyzer, electricity and water are combined to create oxygen and hydrogen using the same PEM.

Long-term durability and high performance of such cells has been a concern. However, our testing of prototype cells through multiple charge-recharge cycles has shown that running more than 2000 cycles resulted in only negligible performance degradation. Our testing also demonstrated reversible cells with high performance in both charge and discharge modes.

Energy storage systems with extremely high specific energy (>400 Wh / kg) have been designed with this reversible fuel cell in combination with lightweight pressure vessels to contain the gases that are generated through electrolysis. Possible applications include high-altitude solar-rechargeable aircraft, hybrid energy storage / propulsion systems for spacecraft, zero-emission vehicles, energy storage for off-grid power systems, peak-shaving capacity for electric utilities, and premium power applications.

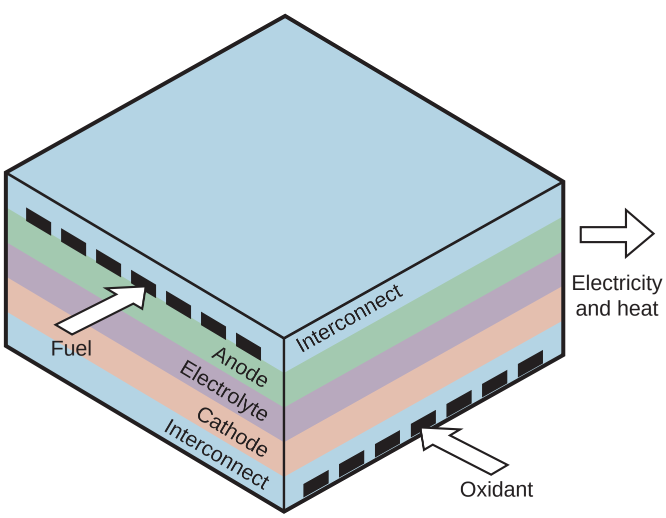
The Solid Oxide Fuel Cell

LLNL's materials-science expertise is improving the power density of solid oxide fuel cells, reducing their operating temperatures, and lowering their fabrication costs. These fuel cells are constructed of ceramic oxide material and operate at elevated temperature to produce electricity and generate useful waste heat. They have several advantages over other energy-producing systems and other fuel cells: no corrosive problems, reduced poisoning effects, no hazardous liquid spills, fuel flexibility, and higher efficiencies possible than all other fuel cells.

Each fuel cell consists of three electrochemical components: a cathode that electrochemically reduces oxygen from air, a solid-oxide electrolyte that ensures the transport of oxygen ions from one side of the cell to the other, and an anode where the fuel is oxidized by combining with the oxygen ions transported through the electrolyte. A single fuel cell generates a low voltage, so many fuel cells must be connected in series, with an electrical interconnect providing contact between cells.

These fuel cells are more efficient when the electrolyte layer is made thinner, reducing resistance losses, but the standard process for depositing the thin layer of electrolyte is delicate, time-intensive, and expensive. We have been developing a new, lower-cost deposition technique—a modified colloidal deposition technique—that in a single step can deposit a high-quality coating that ranges from 1 to 100 micrometers in thickness. These thin films of yttria-stabilized zirconia also reduce the fuel cell's operating temperature by at least 200°C.

We have successfully tested prototype planar cells made with this technology and are now modifying the technique for tubular substrates. We are also experimenting with a graded fuel-cell structure, which progressively changes from the pure anode material to the zirconia electrolyte and finally to pure cathode material. The graded structure alleviates problems with chemical incompatibility and the stress that arises from differences in thermal expansion coefficients.



The modular solid-oxide cells are stacked to produce the desired power output.

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